The Urban Forests of Frederick, Maryland in a Changing Climate

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Introduction:

Climate change has reached Maryland. Trends indicate that temperatures have been increasing overall, but the thermal variability is more problematic. Precipitation patterns also have been variable, with data showing there may be more severe droughts in summer and harsher winter temperatures with strong winds. In addition, more severe storms with heavier rainfall could cause localized flooding and damage to infrastructure. "Climate change is much more than increasing temperatures; increasing climate variability will lead to equal or greater impacts that will need to be addressed," according to the U.S. Forest Service Climate Change Resource Center website[1]. Trees will be impacted by this variability and will need to adapt to thrive.

The survivability of urban tree species in the area will have significant implications for water quality. Trees are the best and most inexpensive way to maintain and improve water quality because they capture sediment and nutrients, provide shade to cool the water, and provide habitat. Urban forests are critical to water quality.

Diversity will remain a key component of managing urban forests in the future. Not all species will be able to survive and thrive. Trees take multiple decades to reach full height and spread so the time to build a resilient canopy is now.

Figure 1: Street trees compete for space with utilities, sidewalks, and buildings, leaving very little soil to provide all their nutrients and water resources.

The particular tree species used in an urban forest setting should focus on an ability to thrive in changing climate and space conditions. Urban forests, particularly street trees, must endure the harshest conditions, and climate change will only make these conditions more extreme. Sidewalks, driveways, parking lots, streets, and utilities are all impediments to root growth. In addition, these urban forests are subjected to road salt, pet urine, excess radiant heat from asphalt and concrete, limited access to water and nutrients, and pruning that allows for foot and vehicle traffic as well as building facades. According to data collected in Philadelphia and other locations[2], the average life span of a street tree is 19 to 28 years, and the annual mortality rate is 3.5 to 5.1 percent. Trees in parks and open spaces will be far less stressed, but may still endure temperature, precipitation, and foot traffic challenges. These changes may push some species farther west or north to areas where temperatures are cooler and precipitation patterns are more normal.

Two of Frederick's ten largest street tree species are Callery pear and Norway maple, well-known for their invasive characteristics. Only four of the ten largest species are native, five if Ginkgo is considered native to the area. This follows a national trend showing that some non-native species may be more hardy than native species when faced with harsh street pit conditions. Trees that can thrive in those conditions are likely to also do well in the less harsh park and landscape settings.

City of Frederick's Largest Street Trees in 2018
Norway maple (*Acer platanoides*)*
Red maple (*Acer rubrum*)
Ginkgo (*Ginkgo biloba*)
Honeylocust (*Gleditsia triacanthos*)
Sweetgum (*Liquidambar styraciflua*)
Callery pear (*Pyrus calleryana*)*
Northern red oak (*Quercus rubra*)
Japanese pagoda tree (*Sophora japonica*)
Littleleaf linden (*Tilia cordata*)
Japanese zelkova (*Zelkova serrata*)
*The City no longer plants these species

Figure 2: The City's largest street tree species.

Some of our native species are already reacting to climate change. Eastern white pine (*Pinus strobus*), often used in landscapes and parks as a screen, is one species that could recede toward colder climates. This species is teetering on the edge in Frederick, because it prefers cooler temperatures and moist, well-drained soils. While it can survive U.S. Department of Agriculture (USDA) Hardiness Zone 3 through 8, higher temperatures and drier weather weaken it, often magnifying the effects of environmental stressors, particularly air pollution. Many white pines in the mid-Atlantic area decline by about age 30 unless grown in perfect conditions. According to "Cultural Disorders of Eastern White Pine,"[3] by Bartlett Tree Experts, "white pine is subject to a greater array of diseases than any other North American tree species." The changing climate will only increase the stress placed on these trees and disrupt the variety of wildlife that they support.

The City of Frederick currently has 20 percent canopy coverage, but a goal to reach 40 percent by 2030.

What will replace the white pines if they don't grow to their full potential in our new climate?

Figure 3: Eastern white pine (Pinus strobus) beginning to show signs of decline.

On the opposite side of the issue are species that may be able to thrive in our new environment that were marginal just 50 years ago. Bur oak (*Quercus macrocarpa*), a Midwestern species that thrives in hotter, drier climates, will likely grow to full potential in the new climate if given enough space. Bur oaks may replace other trees in certain marginal urban areas. This is an example of the species shift that Frederick will need to accommodate as precipitation and temperatures become more extreme and unpredictable.

Understanding Frederick's current canopy also will be important to adapting it for the future. The City of Frederick has 20 percent canopy coverage, according to a 2016 Tree Canopy Assessment[4] and the goal is for 40 percent canopy coverage by 2030. Canopy is the overall measure of tree cover for a given location, and the Assessment shows specifically where more trees could be planted. Maximizing canopy in those spaces, particularly on private residential and homeowner association (HOA) common space lots, will help reduce impacts from increased temperatures. There are likely fewer utility and impervious surface conflicts in residential yards and HOA common spaces than along streets, where space is limited. Trees in parks, HOA common spaces, and private landscapes are more likely to grow to their full potential where they can better contribute to reducing impacts from the urban heat island, reducing energy costs, filtering more stormwater, and helping to capture more particulate matter because of larger canopy and more leaf area.

Precipitation Trends:

There is no doubt that the excessive rains in the summer of 2018 have stressed some trees to the point of failure. Street trees may not have been as severely impacted because there is very little infiltration space in tree pits. However, if the pits are compacted and water sits on top of the soil, the trees may suffer root loss and eventual whole tree failure. In the case of excess rainfall, the trees nearest our waterways could be significantly impacted because of velocity of the stream flow and consistent inundation. Bald cypress (*Taxodium distichum*) may be considered for these spaces because they can withstand permanent inundation, but also will thrive without it, so long as they are near water or are in low areas. Sycamore (*Platanus occidentalis*), hackberry (*Celtis occidentalis*), and black walnut (*Juglans nigra*) also are good choices for floodplain areas, but none will thrive in standing water for extended periods of time.

"…the annual mean precipitation has been above average for the last two decades."

Precipitation changes attributed to climate change are not likely to severely impact these species if they are planted in the right place.

According to the National Oceanic and Atmospheric Administration Centers for Environmental Information State Climate Summaries for Maryland and District of Columbia report[5], the annual mean precipitation has been above average for the last two decades. The report also states that the "annual number of extreme precipitation events (days with more than two inches) averaged 2.5 days per year during 2005-2014 compared to 1.8 days per year during 1950-2004."

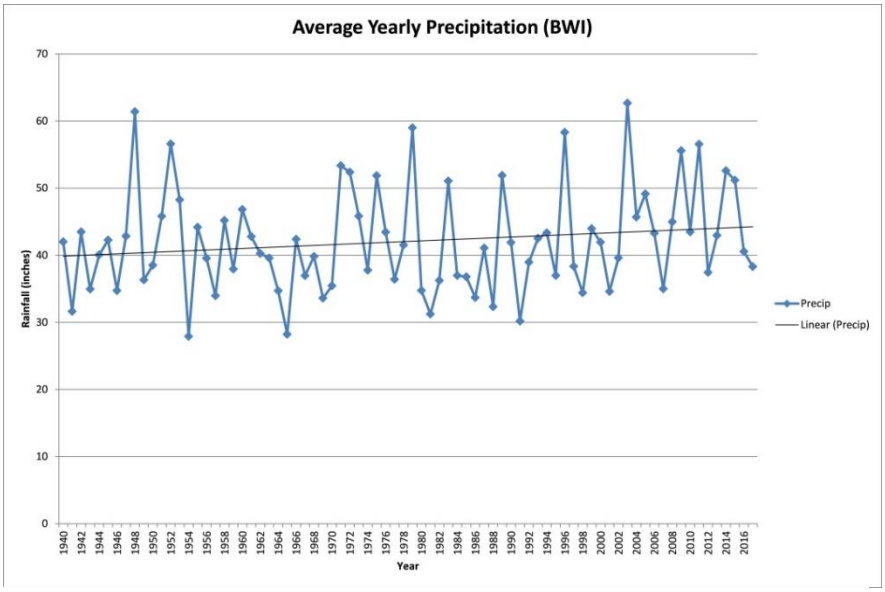

Figure 4. Precipitation at Baltimore-Washington International Airport from 1940 to present.

These extreme precipitation events will lead to increased flooding. According to the U.S. Global Change Research Program's "Global Climate Change Impacts in the United States" report[6] indicated that today's 100-year flood will occur between once per decade to once every 22 years in New York City, depending on the global emissions scenarios. While Frederick is not a coastal city like New York, it will likely be impacted by increased severe storm activity, which could lead to increased flooding.

The flooding events in summer 2018 might prompt a review of 100-year floodplains to determine if they are adequate guidelines for development. Forested floodplains are ideal, but not practical with current allowed facilities in the floodplain, such as sewer lines, paved pathways, stormwater facilities, and other utilities. Increased precipitation will only increase the importance of protecting our floodplain areas with forests.

Figures 4 and 5 show precipitation data from Baltimore-Washington International and Reagan National airports. While there is some indication that precipitation is increasing in the Baltimore area, that same trend is not yet apparent at the more inland data point.

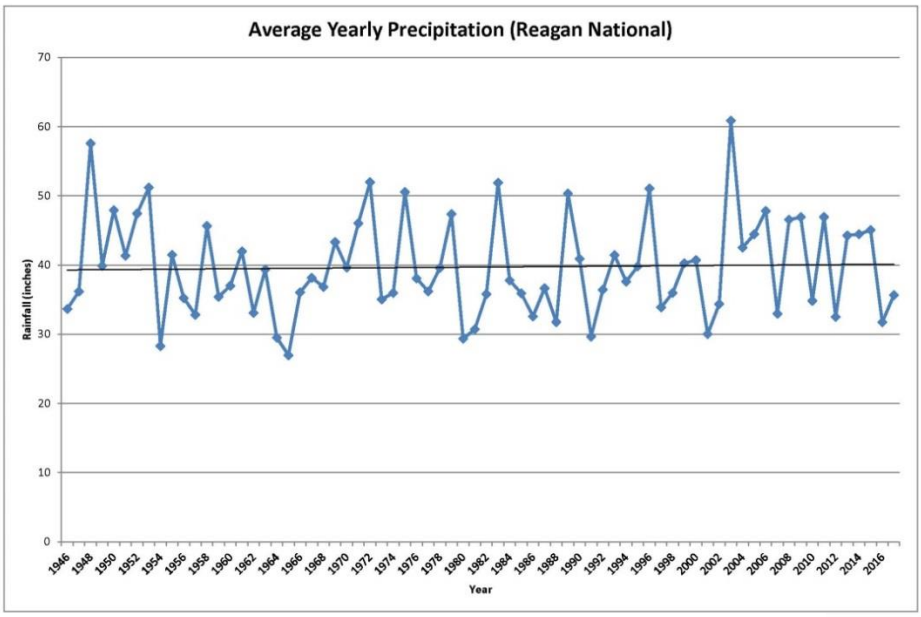

Figure 5. Precipitation at Reagan National Airport from 1946 to present.

"[River] flows will decrease, due to a combination of changing precipitation patterns and increases in evaporation from land and water surface and in transpiration by vegetation," according to the Interstate Commission on the Potomac River Basin's 2015 report "Washington Metropolitan Area Water Supply Alternatives: Meeting the Challenges of Growth and Climate Change"[7]. The report goes on to say that "higher temperatures and changes in precipitation patterns may result in higher than expected water demands due to increased summertime outdoor water use for landscaping and other purposes." The variable future precipitation will demand hardier tree species that are able to withstand both prolonged periods of drought and periodic inundation.

Increased flooding can topple trees, pulling entire root balls out of the soil. Winter storms, such as the one that coated the Northeast in ice in early January 2018, may also become more severe. Ice can break healthy branches and the tops of trees, resulting in damage to infrastructure, homes, and personal property. Resilient tree species will be more likely to survive these severe precipitation events.

Why not a weeping willow (Salix babylonica)?

Weeping willows are not native to the U.S. and their delicate hanging branches can easily be broken in winter storms. In addition, their branch structure is poor, the wood is weak, and the life span is short. While weeping willows make excellent specimen trees in specific locations, especially in wet areas, they are not ideal candidates for building canopy over time.

Figure 6: Large trees need plenty of room for roots and often spill over their allotted space.

As floods become more severe, trees in open park spaces and residential areas will need to be able to survive temporary inundation. While not ideal for planting near structures, trees with extensive root systems and those that like moist soils, such as willow oak (*Quercus phellos*), will be able to withstand longer periods of flooding and can be used in parks and HOA common spaces.

Upland areas typically do not become inundated with storm water or overflow from waterways, but often are subject to dry soils during drought. While northern red oaks (*Quercus rubra*) are only hardy in zones 5 through 8, they can thrive in dry forest soils and somewhat compacted urban soils.

Drought-tolerant trees tend to have deeper and more extensive root systems to access resources that may be found lower in the soil horizon. That said, if a tree is grown in compacted soil, its root system will grow close to the surface of the soil and often slightly above it to access air, despite its typical root growth pattern. Trees grown in these soils may not be well-adapted to drought and will likely need additional resources to thrive, which may be difficult if watering restrictions are in place.

Temperature Trends:

Canopy coverage will be a critical component in mitigating urban heat island effect. According to the U.S. Environmental Protection Agency (EPA)[10], temperatures can be as much as 22°F warmer in urban areas than surrounding less developed regions. Studies show varying energy savings when trees are incorporated into the landscape, but all agree that a large, deciduous shade tree in the right place can provide significant savings in energy costs, particularly in summer. The increased energy used to cool buildings results in more fossil fuels burned, subsequently releasing more harmful pollutants and greenhouse gases into the atmosphere. This creates a tail-chasing cycle by further increasing the energy required to cool buildings.

As temperatures climb, trees may begin to close stomata, the pores on leaves that allow for evaporation and carbon dioxide absorption. As temperatures climb too high, stomata close to preserve moisture in the tree, which means they are also closed to carbon dioxide absorption.[11,12] Excess carbon dioxide, one of several greenhouse gases contributing to a warming climate, comes from burning fossil fuels. Trees near concrete or asphalt may be exposed to higher radiant heat, which also could stress them into

closing their stomata earlier than those trees in forested settings or in yards. This pattern is already beginning to cause increased tree deaths in the tropics. Selecting trees that are able to withstand higher and lower temperatures ensures survival in a changing climate.

Figure 7: Blackgum (Nyssa sylvatica) leaves turning brilliant red at the beginning of autumn.

Black gum (*Nyssa sylvatica*) is hardy in zones 4 through 9, and swamp white oak (*Quercus bicolor*) is hardy in zones 4 through 8. Both are excellent choices for drought or temporary flooding and can thrive in temperatures down to about -25°F and in hot spells. These two species have shown that they can survive in both forested and urban conditions.

Available temperature data currently shows only a slight increase over time, but may rise more in the coming decades. Though the increased temperature trend at Baltimore Washington International Airport is still less than one degree, as shown in Figure 8, Reagan National Airport shows a two-degree increase since 1946, as shown in Figure 9. Regional data for the Northeast shows an annual average temperature increase of 2°F since 1970, according to the "Global Climate Change Impacts in the United States" report and the National Oceanic and Atmospheric Administration Centers for Environmental Information "State Climate Summaries for Maryland and District of Columbia" report that the average annual temperature has risen by more than 1.5°F in Maryland since the beginning of the 20th century.

The USDA Climate Hubs[8] website reports an observed increase of 10 or more days in the frost-free season length. This equates to a longer growing season, which has, in turn, changed bird migration and other animal patterns. Based on observed temperature changes, Northeast temperatures are projected to rise an additional 2.5 to 4°F in winter and 1.5 to 3.5°F in summer.

The American Horticultural Society's Plant Heat-Zone Map[9] indicates that Frederick is in Zone 6, which now has an average of more than 45 to 60 days above 86°F each year. This shows that trees and woody shrubs will need to thrive in longer-term hot temperatures.

Trees selected for this new urban climate should be able to thrive in both drought and flooding and in multiple hardiness zones. While the Frederick area is comfortably in USDA Hardiness Zone 7, with an annual extreme minimum of 0°F, trees appropriate for Zones 3 through 8 should be considered for planting in Frederick. Not all trees will have such a broad range, but trees with the ability to withstand these extremes are more likely grow to their full potential, if all other growing factors are satisfactory. "Climate conditions suitable for maple/beech/birch forests are

Data shows a 2°F temperature increase in less than a century.

projected to shift dramatically northward, eventually leaving only a small portion of the Northeast with a maple sugar business," according to the "Global Climate Change Impacts in the United States report"[6]. This also has implications for the Frederick area as Cunningham Falls State Park has hosted a Maple Syrup Festival for nearly 50 years. If sugar maples (*Acer saccharum*) are no longer able to thrive in this area, syrup production could be impacted. While Maryland is at the bottom of the list for US maple syrup producers, there are several companies in western Maryland that remain in the business.

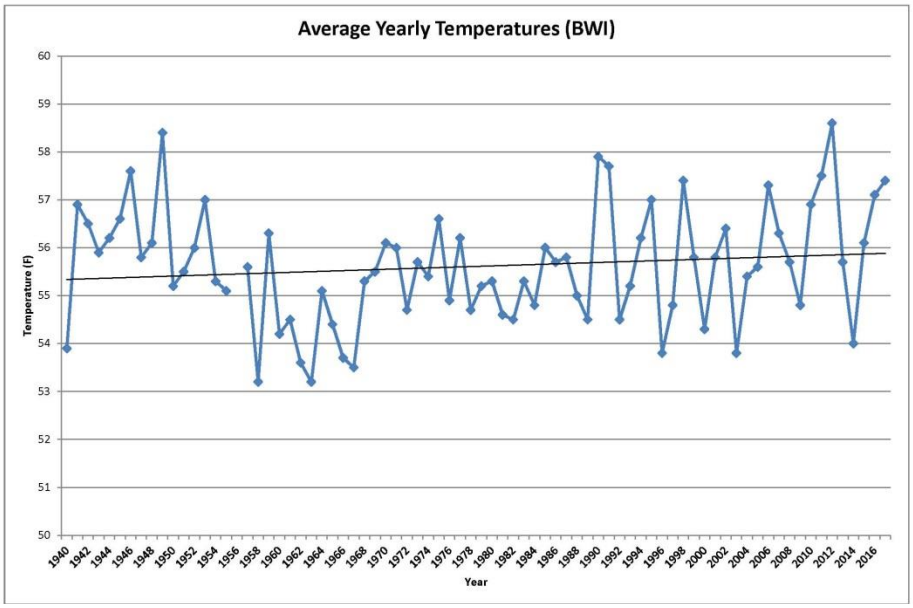

Figure 8. Average temperatures since 1940 at Baltimore-Washington International Airport

In addition to affecting tourism, the loss of sugar maples will also impact our urban forest. Sugar maples are often planted as a replacement for invasive Norway maples (*Acer platanoides*) in urban areas and are extensively encouraged as landscape and street trees, because of their colorful fall foliage. However, with the increased heat from impervious surfaces, sugar maples may not be a suitable long-term selection for our urban forests.

In the future, microclimates may have a larger influence on species selection than regional climate changes. These pockets are where marginal species thrive because they are protected from damaging wind, warmer or cooler soils than surrounding land because of topography, or receive less or more rainfall because of structures and topography.

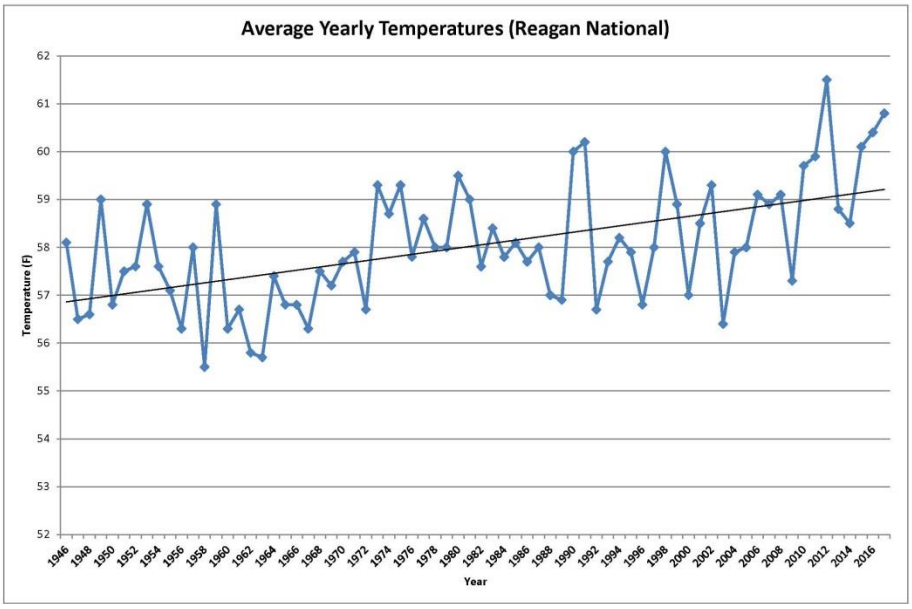

Figure 9. Average temperatures since 1946 at Reagan National Airport

Trees That May Be on the Edge Now:

Some tree species may not be so resilient during the new winter extremes, while others will not be able to thrive in the expected hotter, drier or wetter summer extremes. There are many species that may be on the edge now, and microclimates may dictate how well a species thrives in a specific location. Crepe myrtle, southern magnolia, and sugar maple are a few examples of those species that may be on the edge now.

Crepe myrtle (*Lagerstoemia spp.*) is one popular landscape tree that can succumb to cold winter temperatures. Since the USDA Hardiness Zone map has shifted and may shift again in the future, crepe myrtle should be a species worth considering in small landscapes that provide protection against extreme winter temperatures. There are plenty of other small tree species, such as crabapples (*Malus spp.*), hawthorns (*Crataegus spp.*), and redbud (*Cercis canadensis*), that are comfortably within the growing zones and likely will not be marginalized.

Figure 10: Southern magnolia (Magnolia grandiflora) at Frederick's City Hall

Southern magnolia (*Magnolia grandiflora*) prefers warmer temperatures and can sometimes succumb to injury in

particularly cold temperatures, unless protected from winter winds. With the winter variability, it is unlikely that southern magnolias or crepe myrtles will be less marginalized in the future simply because very few low temperature days can damage or kill these trees. Protection in winter is key. The high summer temperatures are unlikely to kill these trees.

Sugar maple (*Acer saccharum*) also is likely on the edge in Maryland. Requiring cooler temperatures to thrive, this species may not be part of Frederick's urban landscape much longer. As summer temperatures spike, sugar maples will become more stressed and may more easily succumb to diseases or pests.

Trees That May Be on the Edge in the Future:

Figure 11: A river birch (Betula nigra) growing near a waterway, its natural habitat.

River birch (*Betula nigra*) is one species that may suffer from drought in the future. This tree is found along moist river bottoms, but is also a common landscape tree. While it thrives in hot temperatures, unlike many other birches, it cannot tolerate drought. Because it will require extra care and watering, it may not be a suitable tree for urban landscapes in the future. Others that may not thrive in drought conditions of urban landscapes may be willow (*Salix spp.*), paw-paw (*Asimona triloba*), a species that has become a favorite of urban foragers, and sweetgum (*Liquidambar styraciflua*). These species will likely continue to thrive in their native environments along moist bottomlands and river corridors.

Trees that show stress during drought or temperature extremes now may not be able to thrive in this area in the future. Trees that may require supplemental watering are particularly vulnerable to climate change. Should a severe drought occur, restrictions may be placed on landscape watering to protect water supply and minimum flows required to support wildlife. Those restrictions will make it difficult to keep certain species healthy.

Branch Structure and Winds:

Hurricanes, derechos, and tornadoes are all possibilities in the Frederick area. Recent weather patterns indicate that these storms are packing stronger winds and more rainfall. No tree is perfect, but certain species are known to break more often, such as Callery pears (*Pyrus calleryana*), because of their branch

angles, while other species are known to have stronger branch attachments. Even normal winds can break overextended branches or those with weak attachments. A regular pruning schedule for urban trees will help reduce storm damage.

Ginkgo (*Gingko biloba*) is a great example of a tree that has sturdy branch structure requiring less overall maintenance. Oaks (*Quercus spp.*) generally have good branch attachment and structure, though their limbs may become overextended. Hornbeam (*Carpinus caroliniana*) is a small tree with strong branch attachment and overall even shape.

Invasive Species, Diseases, and Pests:

The conifer forests of western U.S., Canada, and Alaska have all been hit hard by bark beetles, whose populations have thrived because of climate change. Without harsh winter temperatures to keep them in check, sometimes two generations of beetles are emerging during the warm springs and summers. Larvae are surviving winter, emerging earlier in spring, maturing, and laying eggs earlier in the year. The second generation of larvae mature and lay eggs before the season ends. Bark beetles kill the trees, and with the extended drought in the western states, those standing dead trees become a tinderbox for wildfire. This is not the only example of a pest's impact worsened by climate change.

Figure 12: Gypsy moth caterpillars are active in mid-May through June and defoliate many tree species.

Gypsy moth, which affects the oaks and other species in the U.S., including Frederick's forests, can be destructive after several years. Gypsy moths eat leaves, which can stress trees over several years of defoliation. Coupled with the added stress of drought, trees can succumb to secondary factors, such as diseases and other insect damage after the initial gypsy moth infestation. However, a fungus (*Entomophaga maimaiga*) that attacks only gypsy moths, thrives in wetter weather.

Thousand cankers disease, a fungal pathogen of black walnut that is transmitted by a beetle, was identified in the East only in the last decade. It is unclear whether the fungus will kill all black walnuts (*Juglans nigra*), but it is clear that it damages and significantly devalues the wood. Black walnut is a very hardy and common species in the Frederick area, and researchers are monitoring it to determine how quickly the fungus spreads. The beetle that carries this fungus could have accelerated life stages similar to those of pine bark beetles, which could speed the spread of the fungus. Black walnuts also are a valuable food source for animals, so its loss would be significant to the wildlife in our area if it does succumb to the disease.

There are many more effectively managed pests and diseases today that may become problematic in future years.

Little Tuscarora Creek is home to a genetically distinct brook trout population found nowhere else in the world.

Plan for Succession:

The City can take several steps to prepare the urban forest for a changing climate. The first step is to develop a Climate Action Plan, incorporating urban forestry into mitigation and adaptation strategies. A Climate Action Plan should include the City's baseline Greenhouse Gas Emissions Inventory completed by the University of Maryland's Program for Action Learning in Sustainability (PALS), the overall Greenhouse Gas assessment completed by Metropolitan Washington Council of Governments, the City's Tree Canopy Report, and input from citizens, businesses, and staff. This Plan will also incorporate components of the City's Sustainability Plan. Tree canopy should be a large component of the Climate Action Plan.

The best trees for landscapes, streets, parks, and common spaces should be hardy in both cold and hot temperatures and should be able to withstand moderate drought and periodic flooding. When appropriate, choose trees that can survive in USDA Hardiness Zones 3 through 8 and those that are known to thrive in both lowland and upland areas.

Developers and residents should take advantage of the City's High Performance Buildings Tax Credit. This will encourage energy-efficient building practices, which will reduce the overall carbon footprint of the City and reduce the impact of the urban heat island.

The City would benefit from its own riparian buffer language as part of the floodplain ordinance. Several of the City's streams are critical habitat for ecologically sensitive and rare species. Riparian buffers help protect the waterways by keeping them cool, providing food and habitat, and stabilizing the banks. Updating the City's Land Management Code and/or a separate riparian buffer ordinance will help protect these critical areas.

Street trees that are planted on private property are currently the responsibility of the landowner to maintain. The City may consider establishing a policy of placing an easement on any privately owned street tree that is of specimen size, or 25 inches dbh (diameter at breast height), and maintaining it for the remainder of its life. A significant value to the City's canopy, air quality, water quality, and overall aesthetic appeal, the benefits from these trees would outweigh the management costs.

Carroll Creek watershed is designated as an Ecologically Sensitive Area of the larger Monocacy Watershed, according to the Maryland Department of Natural Resources (DNR) Wildlife Heritage Service. In addition, Little Tuscarora Creek is home to a genetically distinct brook trout population found nowhere else in the world. Development in the floodplain is already prohibited. However, floodplains are often only partially planted to fully meet the developer's planting requirements. The City also

accepts floodplain land as a significant park land requirement from developers, leaving very few active play spaces that are not impacted by flooding. Seventy percent of the developers' park land requirements can be met with floodplain land. Fields are difficult to maintain in floodplain, as they are often closed after heavy rains, need to be remarked frequently, and generally are substandard play spaces. Adjusting the floodplain parks requirement would be ideal to expand riparian forests and the urban canopy, protect water quality, minimize flooding impacts on active play spaces, and provide better play spaces in upland areas.

A final suggestion for reaching tree canopy goals is to create a Tree Commission that reviews appeals from residents to remove large trees. Currently, there is no appeal mechanism for residents who wish to remove a City-owned street tree. The City arborist submits the request and appeal to Maryland DNR for their ultimate approval at this time. A Tree Commission could offer the City's residents an opportunity to appeal within the City.

References:

1. U.S. Forest Service Climate Change Resource Center. https://www.fs.usda.gov/ccrc/
2. Roman, Lara A., "How Many Trees Are Enough? Tree Death and the Urban Canopy" https://www.fs.fed.us/nrs/pubs/jrnl/2014/nrs_2014_roman_001.pdf
3. Bartlett Tree Research Laboratories Technical Report, "Cultural Disorders of Eastern White Pine." https://www.bartlett.com/resources/Cultural-Disorders-of-Eastern-White-Pine.pdf
4. University of Vermont, "Tree Canopy Canopy Assessment Report." 2016. http://www.cityoffrederick.com/documentcenter/view/9362
5. NOAA National Centers for Environmental Information, "State Climate Summaries: Maryland and District of Columbia." https://statesummaries.ncics.org/md
6. National Climate Assessment "Climate Change Impacts in the United States." https://nca2014.globalchange.gov/
7. Schultz, Cherie, et al., "Washington Metropolitan Area Water Supply Alternatives: Meeting the Challenges of Growth and Climate Change." https://www.potomacriver.org/wp-content/uploads/2017/08/ICP17-3_Schultz.pdf
8. U.S. Department of Agriculture Climate Hubs. https://www.climatehubs.oce.usda.gov/climate-impacts/growing-season?field_hub_region_tid=10
9. American Horticultural Society Plant Heat Zone Map. http://ahsgardening.org/gardening-resources/gardening-maps/heat-zone-map
10. U.S. Environmental Protection Agency Heat Island Effect website. https://www.epa.gov/heat-islands
11. Morello, Lauren. "Higher Temperatures Lessen Plants' Ability to Store CO_2," Scientific American, August 20, 2010. https://www.scientificamerican.com/article/higher-temperatures-lessen-plants-ability-to-store-co2/
12. National Aeronautics and Space Administration Earth Observatory website, "Effects of Changing the Carbon Cycle." https://earthobservatory.nasa.gov/Features/CarbonCycle/page5.php

Additional resources:

Ahmed, S.N., et al. “2015 Washington Metropolitan Area Water Supply Study: Demand and Resource Availability Forecast for the Year 2040.” ICPRB Report No. 15-4. https://www.potomacriver.org/wp-content/uploads/2015/08/ICP15-04a_Ahmed.pdf

Maryland Department of Environment. “Maryland’s Greenhouse Gas Reduction Act Plan, October 2013.” http://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/GGRAPlan2012.pdf

McKenney-Easterling, Mary, et al. “The Potential impacts of climate change and variability on forests and forestry in the Mid-Atlantic Region.” Climate Research 14:195-206, 2000. https://www.fs.fed.us/ne/newtown_square/publications/other_publishers/OCR/ne_2000_easterling001.pdf

Meyer, Robinson, “American Trees Are Moving West, and No One Knows Why: Climate change explains only 20 percent of the movement.” The Atlantic, May 17, 2017. https://www.theatlantic.com/science/archive/2017/05/go-west-my-sap/526899/

National Aeronautics and Space Administration Global Climate Change website. https://climate.nasa.gov/effects/

Tallamy, Doug. Bringing Nature Home Best Bets: What to Plant. http://www.bringingnaturehome.net/what-to-plant.html

U.S. Forest Service Climate Change Resource Center website. https://www.fs.usda.gov/ccrc/topics/forest-tree-diseases-and-climate-change